Change Topic: Technical Note 36

This change package accommodates the text changes to support the proposed solution (see table below) within the public Signals-in-Space (SiS) documents. All comments must be submitted in Comments Resolution Matrix (CRM) form.

The columns in the WAS/IS table following this page are defined below:

- **Section Number:** This number indicates the location of the text change within the document.
- **(WAS) <Document Title>:** Contains the baseline text of the impacted document.
- **Proposed Heading:** Contains proposed changes to existing section titles and/or the titles to new sections.
- **Proposed Text:** Contains proposed changes to baseline text.
- **Rationale:** Contains the supporting information to explain the reason for the proposed changes.

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**PROBLEM STATEMENT:**

Current Signal in Space (SiS) documents reference an outdated coordinate conversion standard (Technical Note 21) between earth centered earth fixed (ECEF) and earth centered inertial (ECI).

**SOLUTION: (Proposed)**

Update GPS technical baseline documents to reflect the latest coordinate conversion standard between ECEF and ECI as documented in Technical Note 36.
## Start of WAS/IS for IS-GPS-200E Changes

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<th>Rationale</th>
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<tr>
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<td>Specifications</td>
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<td>Specifications</td>
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<td></td>
<td>Other Publications</td>
<td>GP-03-001 (GPS Interface Control Working Group Charter)</td>
<td>Other Publications</td>
<td>GP-03-001 (GPS Interface Control Working Group Charter)</td>
</tr>
<tr>
<td>30.3.3.5.1</td>
<td>Message type 32, Figure 30-5, provides SV clock correction parameters (ref. Section 30.3.3.2) and earth orientation parameters. The EOP message provides users with parameters to construct the ECEF and ECI coordinate transformation (a simple transformation method is defined in Section 20.3.3.4.3.3.2). The number of bits, scale factors (LSBs), the range, and the units of all EOP fields of message type 32 are given in Table 30-VII. The equations described in this section are based on (International Earth Rotation and Reference Systems Service) IERS Technical Note 21. However, these equations will be updated to a new Technical Note in the next revision.</td>
<td>Message type 32, Figure 30-5, provides SV clock correction parameters (ref. Section 30.3.3.2) and earth orientation parameters. The EOP message provides users with parameters to construct the ECEF and ECI coordinate transformation (a simple transformation method is defined in Section 20.3.3.4.3.3.2). The number of bits, scale factors (LSBs), the range, and the units of all EOP fields of message type 32 are given in Table 30-VII. The equations described in this section are based on (International Earth Rotation and Reference Systems Service) IERS Technical Note 21. However, these equations will be updated to a new Technical Note in the next revision.</td>
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<td>Tech Note 36 Proposed Heading</td>
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<td>Rationale</td>
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</tr>
<tr>
<td>30.3.3.5.1.1</td>
<td>The EOP fields in the message type 32 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 30-II. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in Table 30-VIII. The coordinate systems are defined in Section 20.3.3.4.3.3</td>
<td>The EOP fields in the message type 32 contain the EOP data needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 30-II. The full coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, may be accomplished in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations shown for UT1, xp and yp as documented in Table 30-VIII. The coordinate systems are defined in Section 20.3.3.4.3.3</td>
<td>The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not the Directorate’s responsibility to show users on how to utilize those information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in</td>
<td>how to utilize those information</td>
</tr>
</tbody>
</table>
30.3.3.5.1. An ECI position, $R_{eci}$, is related to an ECEF position, $R_{ecef}$, by a series of rotation matrices as following:

$$R_{ecef} = [A][B][C][D] R_{eci}$$

where the rotation matrices, $A$, $B$, $C$, and $D$, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, $A$, and Earth Rotation, $B$, matrices.

The rotation matrices, $A$, $B$, $C$ and $D$ are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i$th-axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}$$

$$R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The user shall compute the Inertial-to-Geodetic rotation matrix, $ABCD$, using the equations shown in the computations detailed in Chapter 5 of IERS Technical Note 36.
<table>
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<tr>
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<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Table 30-VIII.</td>
<td>Conventions (2010) and equations shown for UT1, xp and yp as documented in Table 30-VIII.</td>
<td>will only provide description on information that is broadcasted in the navigational message. It is not Directorate’s responsibility to show users on how to utilize those information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.</td>
<td></td>
</tr>
<tr>
<td>Element/Equation</td>
<td>Description</td>
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<tr>
<td>------------------</td>
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<td></td>
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</tr>
<tr>
<td>$TDF = t + 51\frac{184}{100}$</td>
<td>Compute Terrestrial Dynamical Time relative to GPS Time $t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$J.E.D. = TDT$ expressed in days of 86400 sec</td>
<td>Compute Julian Ephemeris Date</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$g = \frac{\pi}{180}\left[357.528 + 35999.05 \frac{JED - 2451545}{365.25}\right]$</td>
<td>Compute Mean Anomaly of Earth in its orbit, $g$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$J.B.D. = J.E.D + \frac{0.001658 \sin g + 0.0167 \sin g}{86400s}$</td>
<td>Compute Julian Date in Barycentric Dynamical Time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = \frac{J.B.D. - 2451545}{36525}$</td>
<td>Compute time from J2000 Julian Epoch in Julian Centuries</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>$\zeta = 2306.2181 T + 0.30188 T^2 + 0.017996 T^3$</td>
<td>Compute Precession Fundamental Angles at time $t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$z = 2306.2181 T + 1.09468 T^2 + 0.018203 T^3$</td>
<td>Calculate Precession Matrix at time, $t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\theta = 2004.3109 T - 0.42665 T^2 - 0.041833 T^3$</td>
<td>Compute Mean Obliquity, $\varepsilon$, at time $t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$D = R_3 {-90^0 - z} R_1 (0) R_3 {-90^0 - \zeta}$</td>
<td>Compute Nutation Matrix at time, $t$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\bar{z} = 23^2 26^2 21.448 - 46.815 T - 0.00059 T^2 + 0.001813 T^3$</td>
<td>(&lt;DELETE&gt;)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not the Directorate’s responsibility to show users on how to utilize those information. Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.
Table 30-VIII. Application of EOP Parameters (Part 2 of 2)

<table>
<thead>
<tr>
<th>Element/Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \psi = \sum \frac{E_j}{r_j} \sin \left( \sum \frac{r_j}{r_j} E_j \right)$</td>
<td>Notation in Longitude</td>
</tr>
<tr>
<td>$\Delta \epsilon = \sum \frac{E_j}{r_j} \cos \left( \sum \frac{r_j}{r_j} E_j \right)$</td>
<td>Notation in Obliquity</td>
</tr>
<tr>
<td>$UT_1 = UTC + \Delta UT_1 + \Delta UT (t - t_{EOP})$</td>
<td>Compute Universal Time at time $t$</td>
</tr>
<tr>
<td>$\alpha = \bar{\alpha} + \Delta \psi \cos(\bar{\alpha} + \Delta \epsilon)$</td>
<td>Compute Mean Greenwich Hour Angle</td>
</tr>
<tr>
<td>$B = R_y (\alpha)$</td>
<td>Compute Rotation Matrix at time, $t$</td>
</tr>
<tr>
<td>$A = R_x (\gamma_x) R_y (\gamma_y)$</td>
<td>Compute Polar Motion Matrix at time, $t$</td>
</tr>
<tr>
<td>$ABCD = [A</td>
<td>B</td>
</tr>
</tbody>
</table>

$t$ is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).

The Notation in Longitude and the Notation in Obliquity are as described in The Astronomical Almanac (1983), pp. S23-S26, evaluated at time $T$.

The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate's responsibility to show users on how to utilize that information.

Details for the calculation of inertial-to-Geodetic rotation matrix can be found in IERS TN36. Updated the equations.
<table>
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<tr>
<th>Section Number</th>
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</thead>
<tbody>
<tr>
<td></td>
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<td>for xp and yp to ensure that the derivatives are applied to the second term &quot;PM_X(t-tEOP)&quot; and &quot;PM_Y(t-tEOP)&quot; so that the units work out correctly.</td>
</tr>
</tbody>
</table>

Updated the equation UT1 to ensure that the derivative is applied to the third term "deltaUT1(t-tEOP)" and so that the units work out correctly.
The EOP fields in the message type 32 contain the EOP data needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 20-II. The EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices. The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i^{th}$ - axis ordinate, as follows:

$$R_{ecef} = [A][B][C][D]R_{eci},$$

where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Precession and Nutation, respectively. The EOP fields in the message type 32 contain the EOP data needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 20-II. The EOP fields in the message type 32 contain the EOP data needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 20-II. The EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices. The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i^{th}$ - axis ordinate, as follows:

$$R_{eci} = [A][B][C][D]R_{eci},$$

where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices.

The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i^{th}$ - axis ordinate, as follows:

$$R_{eci} = [A][B][C][D]R_{eci},$$

where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices.

The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i^{th}$ - axis ordinate, as follows:

$$R_{eci} = [A][B][C][D]R_{eci},$$

where the rotation matrices, A, B, C, and D, represent the effects of Polar Motion, Earth Rotation, Nutation and Precession, respectively. The message type 32 specifies the EOP parameters used in the construction of the Polar Motion, A, and Earth Rotation, B, matrices.

The rotation matrices, A, B, C and D are specified in terms of elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i^{th}$ - axis ordinate, as follows:
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<thead>
<tr>
<th>Section Number</th>
<th>Tech Note 36 Proposed Heading</th>
<th>IS-GPS-705 Rev A LS SS and Nav User Segment Interfaces</th>
<th>Tech Note 36 Redlines</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>20.3.3.5.1</td>
<td>The user shall compute the Inertial-to-Geodetic rotation matrix, $ABCD$ using the equations shown in Table 20-VIII.</td>
<td>The user shall compute the Inertial-to-Geodetic rotation matrix, $ABCD$ using the equations shown in accordance with the computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, $xp$ and $yp$ as documented in Table 20-VIII.</td>
<td>The GPS Directorate will only provide description on information that is broadcasted in the...</td>
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</tr>
</tbody>
</table>

computations detailed in Chapter 5 of IERS Technical Note 36: IERS Conventions (2010) and equations for UT1, $xp$ and $yp$ as documented in Table 20-VIII. Figure 5.1 on page 73 of that document depicts the computational flow starting from GCRS (Geocentric Celestial Reference System) to ITRS (International Terrestrial Reference System). Ongoing WGS 84 re-adjustment at NGA and incorporating the 2010 IERS Conventions, are expected to bring Earth based coordinate agreement to within 2 cm. In the context of the Conventions, the user may as a matter of convenience choose to implement the transformation computations via either the Celestial Intermediate Origin (CIO) based approach or the “Equinox based approach”. The EOP parameters for ΔUT1 are to be applied within the “Rotation to terrestrial system” process, and the parameters for $xp$ and $yp$ are applied in the “Rotation for polar motion” process. Users are advised that the broadcast message type 32 EOP parameters already account for zonal, diurnal and semi-diurnal effects (described in Chapter 8 of the IERS Conventions (2010)), so these effects should not be further applied by the user.

The relevant computations utilize elementary rotation matrices $R_i(\alpha)$, where $\alpha$ is a positive rotation about the $i$th-axis ordinate, as follows:

$$R_1(\alpha) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & \sin(\alpha) \\ 0 & -\sin(\alpha) & \cos(\alpha) \end{bmatrix}, \quad R_2(\alpha) = \begin{bmatrix} \cos(\alpha) & 0 & -\sin(\alpha) \\ 0 & 1 & 0 \\ \sin(\alpha) & 0 & \cos(\alpha) \end{bmatrix}$$

$$R_3(\alpha) = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

The user shall compute the Inertial-to-Geodetic rotation matrix, $ABCD$ using the equations shown in Table 20-VIII.
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<tr>
<th>Section Number</th>
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<th>IS-GPS-705 Rev A LS 55 and Nav User Segment Interfaces</th>
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<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td>navigational message. It is not Directorate's responsibility to show users on how to utilize those information.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Details for the calculation of Inertial-to-Geodetic rotation matrix can be found in IERS TN36.</td>
</tr>
<tr>
<td>Section Number</td>
<td>Tech Note 36 Proposed Heading</td>
<td>IS-GPS-705 Rev A LS 55 and Nav User Segment Interfaces</td>
<td>Tech Note 36 Redlines</td>
<td>Rationale</td>
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</tr>
<tr>
<td>20.3.3.5.1</td>
<td>Table 20-VIII. Application of DOP Parameters (Part 1 of 2)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Element/Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDT = t + 515184</td>
<td>Compute Terrestrial Dynamical Time relative to GPS Time t</td>
</tr>
<tr>
<td>J.E.D. = TDT expressed in days of 86400 sec</td>
<td>Compute Julian Ephemeris Date</td>
</tr>
<tr>
<td>g = \frac{x}{180°} \left[ 357°55'28'' + 35999'05'' \frac{\text{J.E.D.} - 2451545}{36525} \right]</td>
<td>Compute Mean Anomaly of Earth in its orbit, g</td>
</tr>
<tr>
<td>J.B.D. = J.E.D. + \frac{6901658\sin g + 0.0167\sin g}{86400s}</td>
<td>Compute Julian Date in Barycentric Dynamical Time</td>
</tr>
<tr>
<td>T = \frac{J.B.D. - 2451545}{36525}</td>
<td>Compute time from J2000 Julian Epoch in Julian Centuries</td>
</tr>
<tr>
<td>\zeta = 2306°21'81'' T + 0°31'18.88'' T^2 + 0°017998'' T^3</td>
<td>Compute Precession Fundamental Angles at time t</td>
</tr>
<tr>
<td>z = 2306°21'81'' T + T \cdot 0.09468 T^2 + 0°016203'' T^3</td>
<td></td>
</tr>
<tr>
<td>\theta = 2004°31'09'' T - 0°42'665 T^2 - 0°041833'' T^3</td>
<td></td>
</tr>
<tr>
<td>D = R_3(-30° - z) R_1(\theta) R_3(30° - \zeta)</td>
<td>Calculate Precession Matrix at time, t</td>
</tr>
<tr>
<td>\bar{\epsilon} = 23°26'21.448 - 46°815 T - 0°00059 T^2 + 0°0018137 T^3</td>
<td>Compute Mean Obliquity, \bar{\epsilon}, at time t</td>
</tr>
<tr>
<td>C = R_4(\bar{\epsilon} + \Delta \psi) R_3(-\Delta \psi) R_1(\bar{\epsilon})</td>
<td>Compute Nutation Matrix at time, t</td>
</tr>
</tbody>
</table>

The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate’s responsibility to show users on how to utilize those information.
### Table 20-VIII. Application of EOP Parameters (Part 2 of 2)

<table>
<thead>
<tr>
<th>Element/Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \psi = \sum_{i} \sin \left( \sum_{j} E_{ij} \right)^{\dagger}$</td>
<td>Nutation in Longitude</td>
</tr>
<tr>
<td>$\Delta \epsilon = \sum_{i} \cos \left( \sum_{j} E_{ij} \right)^{\dagger}$</td>
<td>Nutation in Obliquity</td>
</tr>
<tr>
<td>$UT1 = UTC + \Delta UT1 + \Delta UT1(t - t_{EOP})$</td>
<td>Compute Universal Time at time $t$</td>
</tr>
<tr>
<td>$\alpha = UT1 + \Delta UT1 + \Delta UT1(t - t_{EOP})$</td>
<td>Compute Universal Time from J2000 Julian Epoch in Julian Centuries</td>
</tr>
<tr>
<td>$\alpha = \alpha + \Delta \psi \cos(\epsilon) + \Delta \epsilon$</td>
<td>Compute True Greenwich Hour Angle</td>
</tr>
<tr>
<td>$B = R_{y} \left( \alpha \right)$</td>
<td>Compute Rotation Matrix at time $t$</td>
</tr>
<tr>
<td>$A = R_{y} \left( \alpha \right) R_{x} \left( \gamma \right)$</td>
<td>Compute Polar Motion Matrix at time $t$</td>
</tr>
<tr>
<td>$x_{P} = PM_{X} + PM_{X}(t - t_{EOP})$</td>
<td>Polar Motion in the x-axis</td>
</tr>
<tr>
<td>$y_{P} = PM_{Y} + PM_{Y}(t - t_{EOP})$</td>
<td>Polar Motion in the y-axis</td>
</tr>
</tbody>
</table>

1. UT1 is GPS system time at time of transmission, i.e., GPS time corrected for transit time (range/speed of light).

The GPS Directorate will only provide description on information that is broadcasted in the navigational message. It is not Directorate’s responsibility to show users on how to utilize those information.
End of WAS/IS for IS-GPS-705A
## IERS Technical Note 36

The EOP fields in subframe 3, page 2 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 3.5-2. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in Section 30.3.3.5.1.1 and Table 30-VIII of IS-GPS-200. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.

### Table 1: IS-GPS-800A Changes Guide

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<th>Tech Note 36 Redlines</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td></td>
<td></td>
<td>IERS Technical Note 36 International Earth Rotation and Reference System Technical Note 36</td>
<td>ECEF-ECI conversion details can be found in IERS TN36.</td>
</tr>
<tr>
<td>3.5.4.2.3</td>
<td></td>
<td></td>
<td></td>
<td>ECEF-ECI conversion details can be found in IERS TN36.</td>
</tr>
</tbody>
</table>

The EOP fields in subframe 3, page 2 contain the EOP needed to construct the ECEF-to-ECI coordinate transformation. The user computes the ECEF position of the SV antenna phase center using the equations shown in Table 3.5-2. The coordinate transformation, for translating to the corresponding ECI SV antenna phase center position, is derived using the equations shown in Section 30.3.3.5.1.1 and Table 30-VIII of IS-GPS-200. The coordinate systems are defined in Section 20.3.3.4.3.3 of IS-GPS-200.